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A-7 ALOFT HARDWARE REQUIREMENTS ENVIRONMENTAL ANALYSIS

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Environmental and operational testing of a fiber-optic interface was conducted to determine suitability of fiber-optic cables, connectors, and LED module for use aboard the A-7 aircraft.

PREFACE

Fiber-optic interface components for the navigation and weapon-delivery systems of the A-7 aircraft were subjected to preliminary environmental tests. These tests are described and the results obtained are presented in this technical document.

This work was performed for the ALOFT program by the Design Engineering Division, Code 4400, for the Air System's Program Office, Code 1600. The work was sponsored by Mr. A. O. Klein, AIR-360G.

SUMMARY

OBJECTIVE

Perform preliminary environmental tests on components to be used in a fiber-optic interface aboard the A-7 aircraft. Components to be tested include fiber-optic cables, bulkhead connectors, and an LED module. The components are to be examined for their physical properties and are to be tested as a system at combined altitude-temperature conditions, vibration levels, and shock levels considered typical of the environmental parameters likely to be encountered during operation of the A-7 aircraft.

RESULTS

Fiber-optic cables were vibrated at worst-case levels expected to occur on the A-7. The cables were also vibrated at both high and low temperature extremes of the A-7 operation. The cables were subjected to additional tests when, as part of a system comprising bulkhead connectors and an LED module, tests were run at combined altitude-temperature conditions, vibration levels, and shock levels likely to occur during A-7 operation. Degradation of all components was observed to be less than ten percent. No optical degradation nor fiber breakage was noted on the fiber-optic cables at temperatures up to 71°C. A higher temperatures, some epoxy extrusion took place, resulting in small losses. No optical degradation nor fiber breakage occurred during vibration or shock.

The fiber-optic bulkhead connectors held 30 psi during the entire range of tests, including simulated altitude conditions of 70,000 feet at -54°C and +35°C, and high-temperature tests to 95°C. The optical losses of three bulkhead connectors, using a diffused white-light source for measurement, were 2.56 dB, 2.80 dB, and 2.97 dB. The last connector had a loss of 2.62 dB using an LED module operating at 845 nm.

The LED module output power degraded by about ten percent during the entire temperature-altitude tests. The module case showed signs of environmental damage after these tests. No degradation was noted during the shock and vibration tests. The LED module was found to be very temperature-dependent. At 95°C, the light output power was down 3 dB referenced to the 25°C level. The light output power was up 3 dB at -54°C referenced to the 25°C level.

In a separate test, two LED types supplied by IBM were measured for power output versus temperature. They were then thermally shocked. No degradation nor failures occurred.

RECOMMENDATIONS

The tests revealed that the fiber-optic cables and pressurized bulkhead connectors met the requirements of MIL-E-5400P, Class 2. The fiber-optic cables tested used a steel monocoil in their construction. At present, these are the only cables capable of surviving

the military environment. Future systems will require the use of non-metallic mono-coil construction.

Sources and detectors which meet military requirements will be needed for ALOFT and other future programs. The source module which was tested was not packaged to meet military requirements and will not be used in the ALOFT program which will use sources and detectors presently being designed by IBM. A fiber optic repair kit will also be needed for future systems. NELC is developing a requirement for the ALOFT program.

The ALOFT system will not affect safety-of-flight requirements for the A-7 aircraft.

It was obvious from the tests that fiber-optic components can be designed to survive military environmental stresses. Such items should be made available as off-the-shelf items.

ADMINISTRATIVE INFORMATION

This work was performed for the ALOFT program by the Design Engineering Division, Code 4400, Naval Electronics Laboratory Center, for the Air System's Program Office, Code 1600. The work was sponsored by Mr. A.O. Klein, AIR-360G.

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INTRODUCTION

The Navy Electronics Laboratory Center (NELC) has contracted with International Business Machines, Federal Systems Division, to design and build a fiber-optic interface for the navigation and weapon systems of the A-7 aircraft. Preliminary environmental tests were performed on possible components to be used in this interface. Components which were tested included fiber-optic cables manufactured by Valtec, bulkhead connectors manufactured by NELC, and an LED module manufactured by General Electric Company. The components were examined for their physical properties and were tested as a system at combined altitude-temperature conditions, vibration levels, and shock levels considered to be typical of the environmental parameters likely to be encountered during operation of the A-7 aircraft. [1]

CONNECTOR LOSS MEASUREMENTS

Two methods were used to measure the connector loss of the NELC single-channel bulkhead connectors. Three of the sample connectors were measured using a diffused white-light source. One of these connectors (the third) was also measured using the General Electric LED module operating at 845 nanometers. A standard reference cable was used throughout the tests to guarantee that the source did not change. The detector was a UDT 40A Optometer, the calibration of which was traceable to NBS standards.

For each of the three connectors, a one-foot test cable was constructed and measured. The cable was then cut in the center of its length and the terminals were epoxied on the ends. After polishing, the two terminal ends were mated in the connector. The terminals were then tightened one-eighth turn beyond finger-tight. The cable was then measured and the loss was calculated from the two measurements. After repeated measurements of the same one-foot continuous cable in the test fixture, the error ascribable to the test set-up was found to be plus or minus two percent. An additional variation of plus or minus two percent was found in the repeated mating and unmating of the connector. Table 1 presents a summary of the measurements.

TABLE 1. CONNECTOR MEASUREMENTS.

	LOSS		BREAKAGE	
Connector Number	Diffused Source	LED Source	Pre-connector Insertion	Post-connector Insertion
1	2.56 dB		0	1/0
2	2.81 dB		1	1/0
3	2.97 dB	2.62 dB	0	0/0

1. Environmental Definition Analysis Report, Report No. 2-50360/4R-5738, Vought Systems Division, LTV, September 1974.

CABLE PARAMETERS

The physical, optical, and electrical parameters of the cables were investigated.

PHYSICAL PARAMETERS

The physical properties of the fiber optic cables under test were found to be very good. In all tests, except the cyclic flexure test*, the cables performed in a manner superior to most commercially available medium-loss cables. The most important test performed was that of measurements of cable length at the A-7 aircraft survey. The cables were run through the aircraft simulating an actual installation. No breaks occurred. Other tests are described in the following paragraphs. Test results are presented in Appendix A.

The cable contained 260 fibers in a bundle diameter of 0.045 inch. The bundle was surrounded by a metal monocoil and a PVC jacket. Cable diameter varied between 0.115 and 0.120 inch. The cable weight was 1.31 pound per hundred feet and one terminal weighed 0.0053 pound.

TENSILE TEST

A tensile force was applied to the terminals of a three-foot section of cable. The light transmission was monitored during the test. Breakage took place above 40 pounds. Total breakage took place at 53 pounds. All breakage was uniform along the length of the cable. There was no evidence of epoxy-terminal bond separation.

MANDREL TEST

A three-foot section of cable was pulled around a half-inch diameter mandrel at a 90° angle. Breakage began at 30 pounds and total breakage took place at 38 pounds. All breaks took place at the bend.

CYCLIC FLEXURE

A one-foot cable was flexed around a one-inch diameter mandrel to 90°. One cycle represented one ±90° bend. Breakage began at 4800 cycles. At 6800 cycles, 20 percent breakage took place*. At this point the PVC jacket was cut back and the metal monocoil was examined. The monocoil was found to have broken causing all of the breakage of the fibers

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*Later tests on a cable with a different monocoil indicated that the cable could survive over 16,000 cycles without any additional breakage.

TWIST TEST

A three-foot cable was twisted along its axis for the specified number of turns and then was twisted back to its original position. Then the cable was twisted in the opposite direction for the specified number of turns. Breakage began at 18 turns. Thirty-three percent breakage took place at 30 turns.

BEND RADIUS TEST

Five wraps of the cable around a quarter-inch diameter mandrel resulted in no breakage. Five wraps around a 0.128-inch diameter mandrel resulted in 63 percent breakage.

OPTICAL PARAMETERS

A cable loss measurement was made at 900 nanometers using six lengths of cable. The measured loss was 854 dB/Km. A relative transmission measurement was made between 660 nanometers and 1130 nanometers. This measurement is shown in Appendix A. When a 48-foot section of cable was illuminated with a diffused white-light source, the half-angle at which the cable power output was down 3 dB was 20 degrees.

CABLE ASSEMBLY AND ELECTRICAL PARAMETERS

Throughout the tests, Devcon "5-minute" epoxy was used in the assembly of the terminal ends. This epoxy held up well during the environmental tests which will be described later. In preparing the cables for the tests, standard wire strippers and cutters ("dykes") were used to cut back the PVC jacket and monocoil before epoxying. No stress relief was used. It was found, however, that unless proper care was taken in the assembly, the monocoil would make contact with the brass terminal ends and create a ground loop through the cable. During the epoxying process, if the PVC jacket is stretched slightly to cover the monocoil, no shorting occurs. Two cables were fabricated using this technique and their electrical properties were measured with a capacitance bridge. These measurements are shown in table 2. (The capacitance of standard radio-frequency cables is usually above 10 pF/foot.)

TABLE 2. CABLE ELECTRICAL PARAMETERS

Cable	Length	Capacitance (between terminals)	Resistance
1	13.5 inches	1.6 pF	11.5×10^5 ohms
2	15.75 inches	2.0 pF	9.5×10^5 ohms

A destructive voltage-breakdown test was performed on these samples using a transmitter operating at 3.6 MHz, a frequency inside the band (3 to 6 MHz) at which electrical cables usually break down at the lowest applied voltage. Cable 1 broke down at 2200 volts, and cable 2 broke down at 1650 volts.

The observed data led to the conclusion that, for use in the A-7 aircraft, no ground-loop problems would be created using the metal monocoil fiber-optic cables.

ENVIRONMENTAL TESTS

Operating and non-operating environmental tests were conducted on the components of the fiber-optic interface under conditions which closely approximated the environments expected during operation of the A-7 aircraft. It was found that the A-7 environment was very close to (but less severe than) the environment specified in MIL-E-5400P, Class 2, and the accompanying environmental test specification, MIL-T-5422F. A comparison of these environments is shown in table 3. The temperature-altitude test of MIL-T-5422F was selected to simulate the A-7 temperature-altitude extremes. Selected pages from specification MIL-T-5422F are contained in Appendix C which lists temperature-altitude test steps, vibration levels, operating temperatures, and a qualification test list to meet MIL-E-5400P requirements.

TABLE 3. ENVIRONMENTAL PARAMETERS

A-7 worst-case environment	MIL-E-5400P, Class 2
Operation (continuous) -54°C to 70°C	-54°C to 71°C
Operation (intermittent) 84°C, 30 minutes	95°C, 30 minutes
Storage temperature -62°C to -65°C	-62°C to 95°C

The components subjected to the environmental stresses included fiber-optic cables, bulkhead pressure connectors, and a light-emitting diode (LED) module. (A related test on two types of LED devices for power output versus temperature and thermal shock is presented in Appendix B.)

The components were assembled into two systems. System 1 was comprised of the LED module, two bulkhead connectors, and three fiber-optic cables. An additional fiber-optic cable was used as an extension to a detector outside the environmental test fixture to monitor performance during the tests. One bulkhead connector was threaded into a thick plate without a packing nut. The other was mounted on a 50-mil thick piece of aluminum with a packing nut. These mountings simulated two different mountings on an aircraft. The measured loss of this system (1), including LED and detector coupling, 13 feet of cable and three connectors, was 27 dB. This system was similar to that of the fiber-optic one aboard the A-7 aircraft which uses three connectors and 27 feet of fiber-optic cable.

The 13-foot section of test cable had a measured loss of 854 dB/Km. A schematic of this system (which was used for temperature-altitude, vibration, and shock tests), as installed in a temperature-altitude chamber, is shown in figure 1.

System 2 was comprised of three bulkhead connectors and three cables. Cable 3 had a length of one foot, and cables 6 and 7 were each three feet in length. A schematic of this system as installed in a pressure chamber is shown in figure 2. System 2 was used in the temperature-altitude tests only.

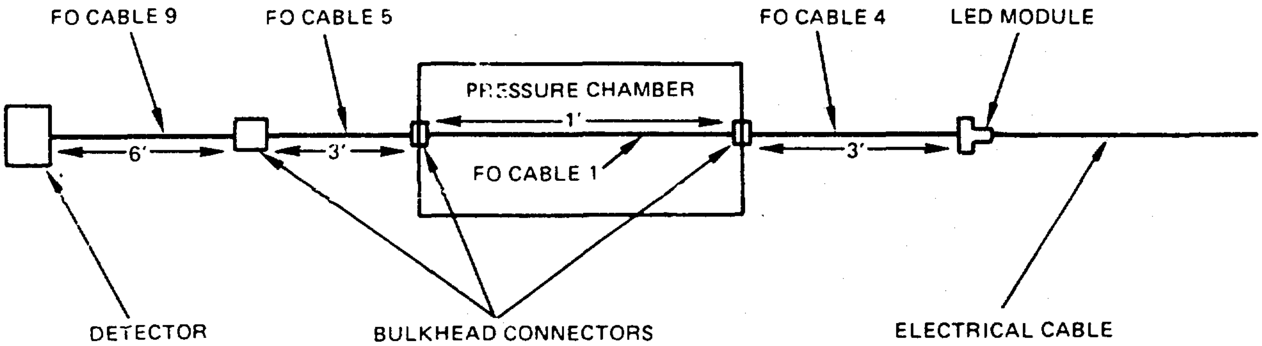

Figure 1. System 1 schematic (shown in pressure chamber).

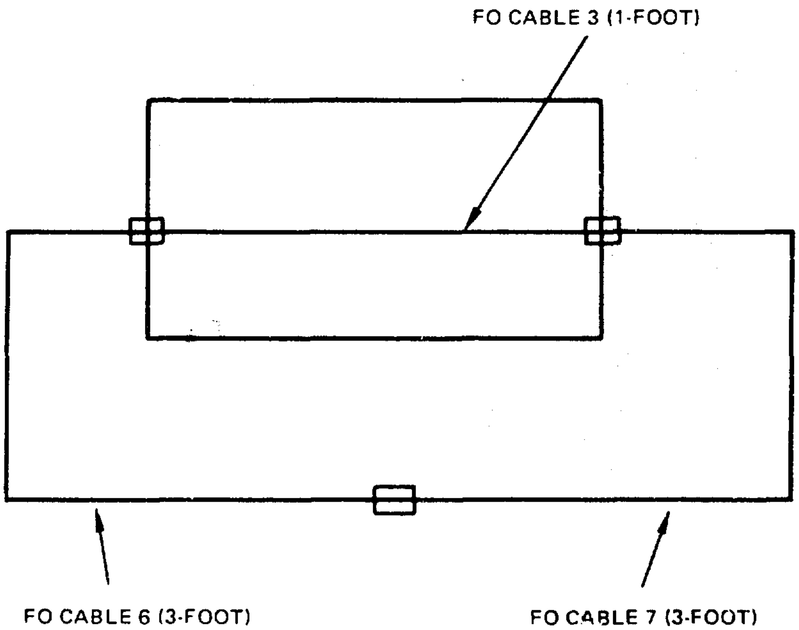

Figure 2. System 2 schematic (shown in pressure chamber).

TEMPERATURE-ALTITUDE TESTS

The steps called for in the test specification were rearranged during the test operation to approach the high-temperature extremes last. This rearrangement was valid according to specification MIL-T-5422F which calls out the steps as independent operations which can be performed in any order. The rearrangement was made for two reasons: the LED module was rated to operate only at 75°C, not over the range of 85° to 95°C (as called out in the specification) and because steps 5 and 6 were to be performed twice, once at a temperature of 85°C to qualify for Class 1 operation and again at 95°C to qualify for Class 2 operation.

The following summary lists the test steps in the order of their performance. During these tests, equipment performance was monitored. This performance data is shown in Appendix D. Since the cables and connectors exhibited very little, if any, degradation during the tests, the performance data is that of LED module operation.

The following test steps were taken directly from specification MIL-T-5422F.

Step 1. Non-operating at -62°C for two hours.

Step 2. LED module switched ON and OFF three times at -54°C at the lowest operating condition (power supply (dc) = 4.75V, input (dc) = 2.0V). Performance tests were run at the end of each temperature-altitude test step. These performance tests were: power output monitored with dc and ac signals (100 kHz, 1 MHz, and 10 MHz), LED module and heat-sink temperatures monitored, worst-case dc "1" and "0" light levels recorded, and photographs taken of output waveforms at 100 KHz, 1 MHz, and 10 MHz using worst-case "1" and "0" levels with a silicon avalanche detector.) The pressure of the chanber was checked at 30 psi at each step for about one hour.

Step 3. LED module operated at high-voltage levels (5.25 Vdc/4.0 Vdc) at -54°C and altitude of 70,000 feet.

Step 4. LED module operated at high-voltage levels, four times, at -10°C in the presence of frost and moisture.

Step 9. LED module operated at high dc voltage levels for four hours at 36°C and an altitude of 50,000 feet.

Step 10. LED module operated at high dc voltage levels for 30 minutes at 60°C at an altitude of 50,000 feet, then turned OFF for 15 minutes. This operation was repeated four times.

Step 11. LED module operated at high dc voltage levels for four hours at 10°C and an altitude of 70,000 feet.

Step 12. LED module operated at high dc voltage levels for 30 minutes, then turned OFF for 15 minutes. This was repeated four times at 35°C and an altitude of 70,000 feet.

At this point in the test, the components were moved to another chamber where higher temperature levels could be obtained. An ambient temperature check was run on the cables and connectors of both systems using a standard white-light source instead of the LED module. All cable and connector measurements were found to be identical to the ones made at the beginning of the test. No cable or connector degradation was found at this point. The LED module was also checked but degradation data cannot be substantiated since the exact temperature conditions were not reproduced.

A summary of system parameters using the LED module is shown in table 4.

TABLE 4. SYSTEM PARAMETERS

System 1 (before test)	System 1 (after Step 6 using LED module)
6.7 μW	5.75 μW
$T_{air} = 25°C$	$T_{air} = 25°C$
$T_{case} = 42°C$	$T_{case} = 52°C$

After this component check, the high temperature tests were performed.

Step 5. LED stored non-operating for 16 hours at 85°C. (Necessary for Class 1 qualification.)

Step 7. LED operated at high dc voltage levels for 30 minutes, then turned OFF for 15 minutes. This was repeated four times at 85°C.

Step 7. (Repeated) LED operated at high dc voltage levels for 30 minutes, then turned OFF for 15 minutes. This was repeated four times at 95°C. (Necessary for Class 2 qualification.)

Step 5. Repeated storage at 95°C for 16 hours. (Necessary for Class 2 qualification.)

An operational check was performed at the end of each step, including the storage steps.

This completed the temperature-altitude tests of specification MIL-T-5422F. At the conclusion of the high-temperature tests, another ambient check was made of the separate components using a standard white-light source. The results of this check are shown in table 5.

The foregoing data revealed that the cables degraded slightly during the high-temperature tests. Looking at the terminal ends, no additional breaks could be found which could be ascribed to the tests. A small amount of epoxy extrusion was found on many of the terminal ends. This caused a small amount of loss. A photograph of this condition is shown in Appendix D. A total of more than 40 hours of temperature exposure at 85°C and higher, produced less than ten percent degradation of the cables. On the A-7 aircraft, operation at these temperatures occurs only intermittently. A temperature of 85°C will be reached aboard the aircraft only when it is warming up for takeoff on a very hot day.

TABLE 5. COMPONENT CHECK AT AMBIENT TEMPERATURE

Component	Before	After
Cables, 1, 4 and 5 as system including two connectors.	1.55 μW	1.55 μW (no change)
Cable 4, no additional breaks	14 μW	13 μW (7.1% loss)
Cable 5, no additional breaks	14 μW	14 μW (no change)
Cable 1, no additional breaks	15.5 μW	14 μW (9.7% loss)
Cables 3, 6, and 7 as system, including two connectors.	1.75 μW	1.6 μW (8.6% loss)
Cable 6, no additional breaks	12.3 μW	12.0 μW (2.4% loss)
Cable 3, no additional breaks	15.2 μW	14.0 μW (7.9% loss)
Cable 7, no additional breaks	14.0 μW	12.5 μW (11% loss)

The LED module was checked in the system at ambient temperature. Measured results of this test are shown in table 6.

TABLE 6. LED PERFORMANCE

Before test	After test
6.7 μW	6.15 μW (8.2% decrease)
$T_{air} = 25°C$	$T_{air} = 28°C$
$T_{case} = 42°C$	$T_{case} = 38°C$

Some degradation of the LED module occurred. The decrease (as shown in the table) was about eight percent, but the LED module case temperature was higher when the measurement was made before the tests were started. If the temperature of the cases were the same, a larger decrease would be evident. (All measurements were made well after warmup of the LED module.)

The LED module was found to be very much temperature-dependent. Data in support of this is shown in Appendix D. It will be noted that the output doubles when the air temperature goes from 25°C to -54°C, or from 38°C to -39°C, case temperature. The output drops to 40 percent of its starting value when going from 25°C to 95°C (air temperature) or from 38°C to 102°C (case temperature). In both cases, this corresponds to a change of 0.05 dB/°C. By compensating for the difference in temperatures before and after the temperature-altitude tests, the LED degradation would be about 12 percent. At a fixed air temperature, the output of the LED module decreased about 10 percent due to warmup. Selected warmup curves are shown in Appendix E. It takes about five minutes for the output to stabilize.

Throughout the temperature-altitude tests, the bulkhead connectors held at 30 psi ±0.5 psi with no noticeable drop for periods from one to six hours. It should be noted that the terminals were tightened from 1/8 to 1/4 turn beyond finger tight. The bulkhead connectors were tightened to about 120 inch-pounds with a torque wrench.

VIBRATION TESTS

A family of vibration curves for various locations aboard the A-7 aircraft, with and without Gatling gun fire, were supplied by LTV. Worst-case vibration levels were taken from the LTV data and were plotted on the vibration curve of specification MIL-T-5422F, figure 6. This figure is contained in Appendix C. All points of the A-7 vibration fall under curve Ia of the specification which is the standard curve used for qualification of equipment to specification MIL-E-5400P. For this reason, system 1 was tested from 10 to 2000 Hz at the amplitude levels specified in curve Ia.

System 1 was vibrated at room temperature along two axes. One axis was longitudinal to the bulkhead connectors and the LED module (their axis of symmetry). The other axis was perpendicular to the axis of symmetry.

The method outlined in MIL-T-5422F was used. First, a resonance survey was performed on the sample along one axis by slowly varying the frequency from 10 to 2000 Hz. No resonances of the bulkhead connectors, fiber-optic cables, or the LED module could be found.

Then, a three-hour cycling exposure was performed in which the vibration frequency changed logarithmically from 10 to 2000 Hz and back to 10 Hz in 15 minutes. The double amplitude of vibration (and acceleration) used was that shown in figure 6, curve Ia (Appendix C). The LED module was operating at normal dc voltages throughout the test. No degradation of LED module output occurred. No breakage of any of the fibers took place.

This test was repeated for the other axis. No degradation or breakage took place.

One fiber-optic cable (6-foot section) was vibrated at high and low temperatures. This cable was clamped, at 18-inch intervals, with nylon cable clamps after a few turns of electrical tape were wrapped around the PVC at the clamp point. The cable was clamped in a U-shaped pattern with a 2-inch diameter bend at the corners. It was subjected to a resonance search by being vibrated perpendicularly to the longest runs (3 feet). At room temperature, three resonances were noted at 18, 23, and 68 Hz. A resonance dwell of 30 minutes was performed at each of these frequencies. The double amplitude was 36 mils as specified by curve Ia. Afterwards, the cable was cycled from 10 to 2000 Hz in the same manner as before. The total cycling time was one and one-half hours. No optical degradation or fiber breaks took place. One section of cable had a monocoil splice in the center of the 18-inch run. The potting between the PVC jacket and the metal splice was observed to be cracked, but no cracks were found in the PVC itself.

After the cable was cold-soaked for two hours at −54°C, another resonance survey was performed on the cable at low temperature from 10 to 60 Hz. One resonance was

found at 38 Hz. The cable was vibrated at this frequency for one-half hour at 36 mils, double amplitude. The maximum cable excursion was about one-half inch. No optical degradation or breakage occurred.

The cable was then stored at 95°C for two hours and again vibrated. One resonance was found at 18 Hz. The cable was vibrated at 18 Hz for one-half hour at 36 mils at high temperature. The maximum cable excursion was about one inch. Again, no optical degradation or fiber breakage took place.

SHOCK TESTS

A shock of 20g was specified by LTV as the worst case for a carrier-type landing of the A-7 aircraft. System 1 was subjected to six shocks along the longitudinal axis and to three shocks along the transverse axis, each at a level of 20g and for the same duration specified by LTV, 11 milliseconds. The shape of the shock pulse was that of the half sine as specified in MIL-T-5422F which also specifies the 11-millisecond duration. (MIL-T-5422F specifies a design shock test of 15g and a crash safety test of 30g.) No degradation or damage was noted.

CONCLUSIONS

The test results clearly revealed that fiber-optic cables using metallic monocoil construction and the pressurized bulkhead connectors will meet MIL-E-5400P requirements. Future systems will, however, require the use of non-metallic monocoil construction for fiber-optic cables. Such cables, capable of meeting the military environmental requirements, are not available today.

The source module which was tested was not packaged to meet military requirements and will not be used on the ALOFT program. Sources and detectors which meet military requirements will be needed for ALOFT and other programs. The ALOFT program will use sources and detectors now being designed by IBM. NELC is developing such a requirement for the ALOFT program.

The ALOFT system will not effect safety-of-flight requirements for the A-7 aircraft.[2]

It is obvious, from this test program, that fiber-optic components can be designed to survive military environmental stresses. Such components should be made available as off-the-shelf items.

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2. Physical Constraints and Aircraft Installation Requirements Report, Report No. 2-50360/4R-5760, Vought Systems Division, LTV, December 1974.

APPENDIX A

FIBER-OPTIC CABLE PARAMETER DATA

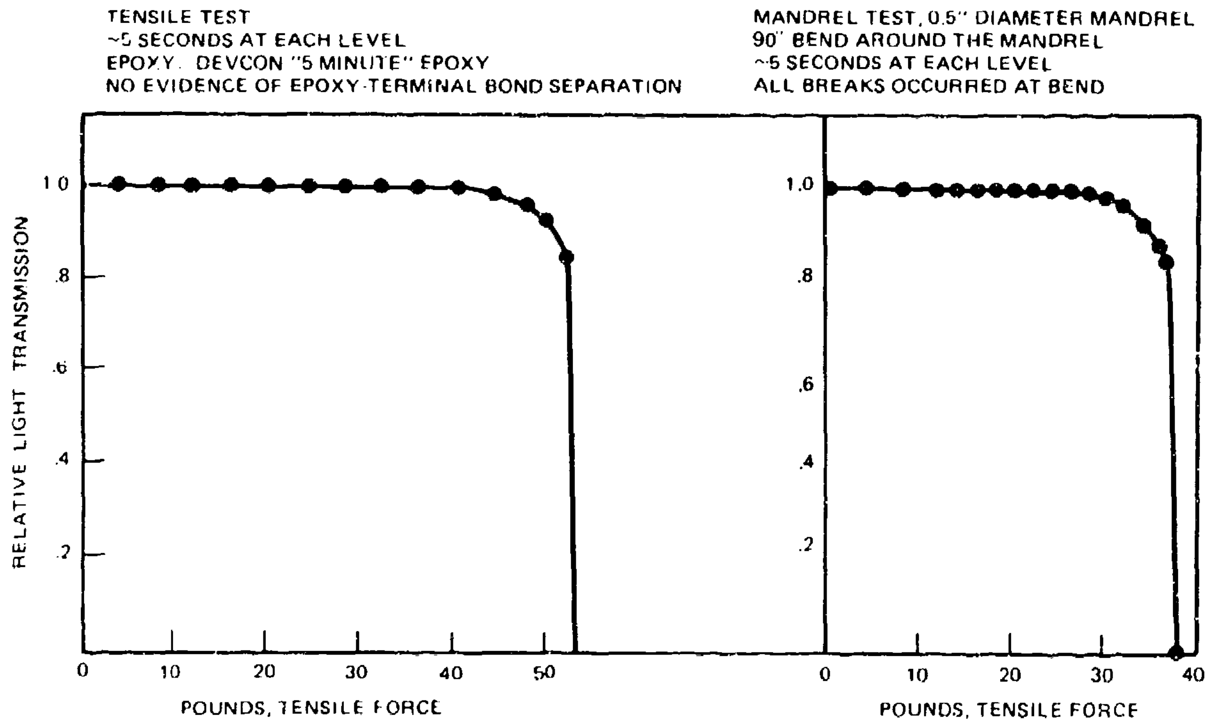

Figure A-1. Tensile and mandrel tests.

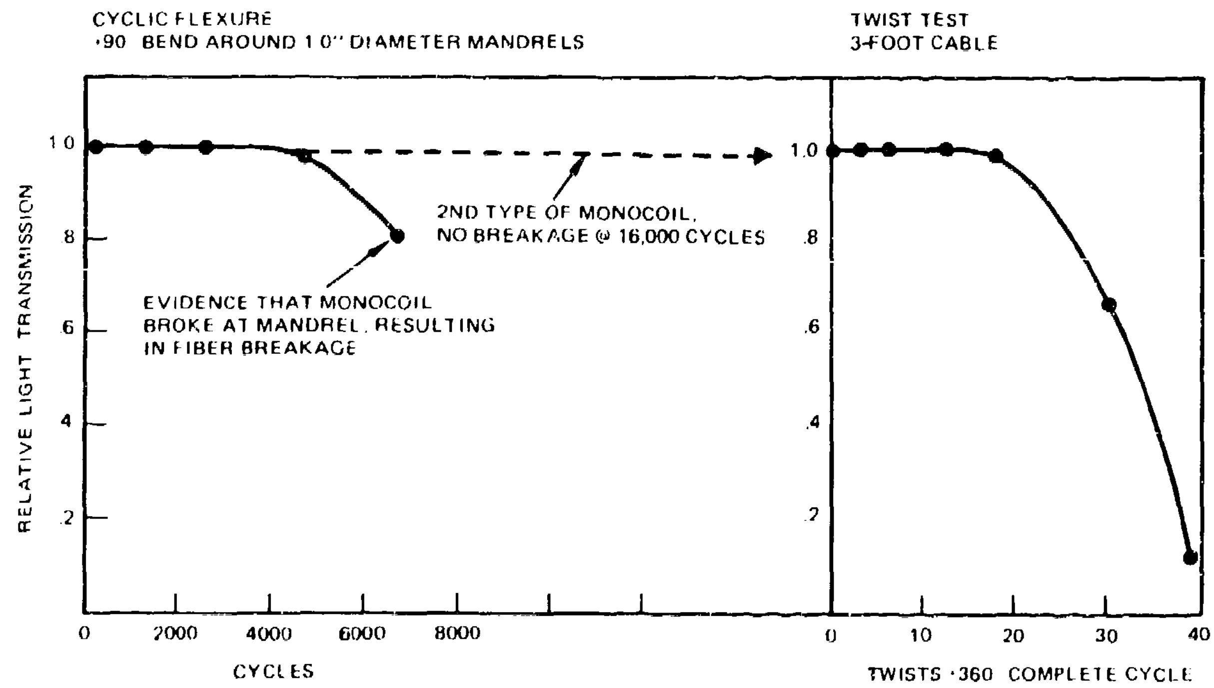

Figure A-2. Cyclic flexure and twist tests.

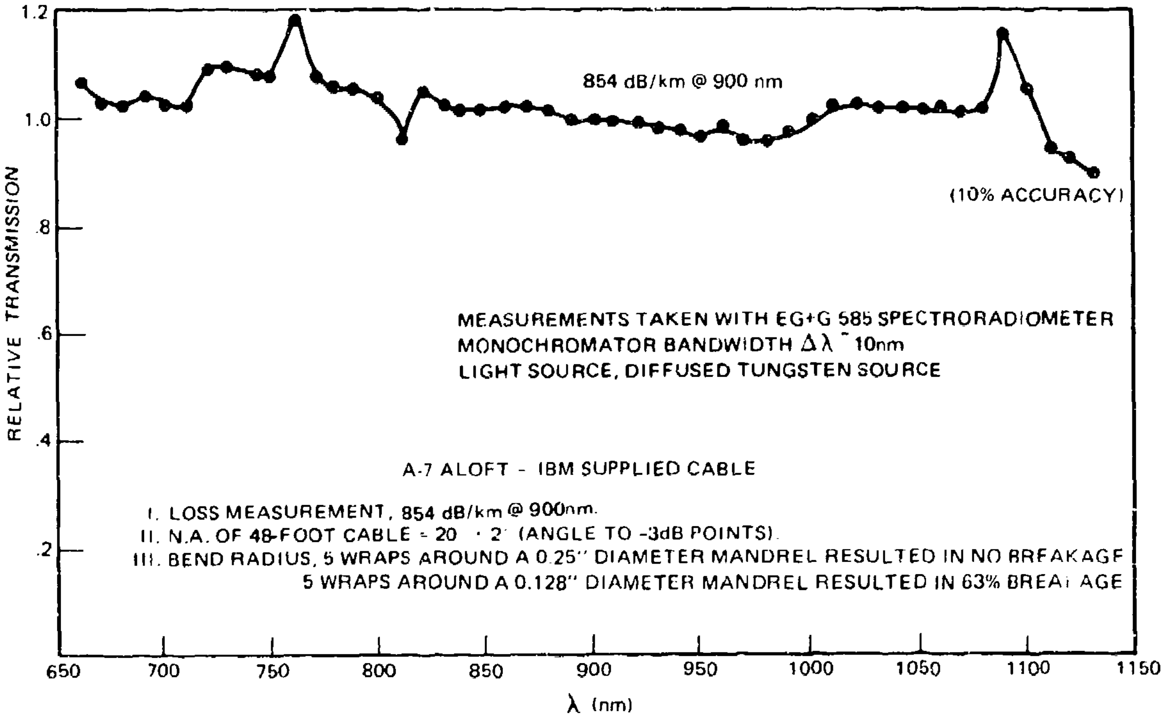

Figure A-3. Optical loss, numerical aperture, bend radius, relative transmission.

APPENDIX B

LED TEMPERATURE AND THERMAL SHOCK TESTS OF SSL-56 AND ML-36 DIODES

TEST DESCRIPTION

Each diode was subjected to seven complete thermal shock cycles (-55°C to +70°C to -55°C). Two ovens were used for this test and the diodes were transferred between temperature environments in less than ten seconds. No failure or degradation of performance as a result of the thermal shock was noted. Figures B-1 and B-2 are plots of output power versus frequency and temperature for the ML-36 and SSL-56 diodes, respectively. Figure B-3 is a plot of output power versus temperature (constant modulating frequency) for the ML-36 and SSL-56 diodes, respectively.

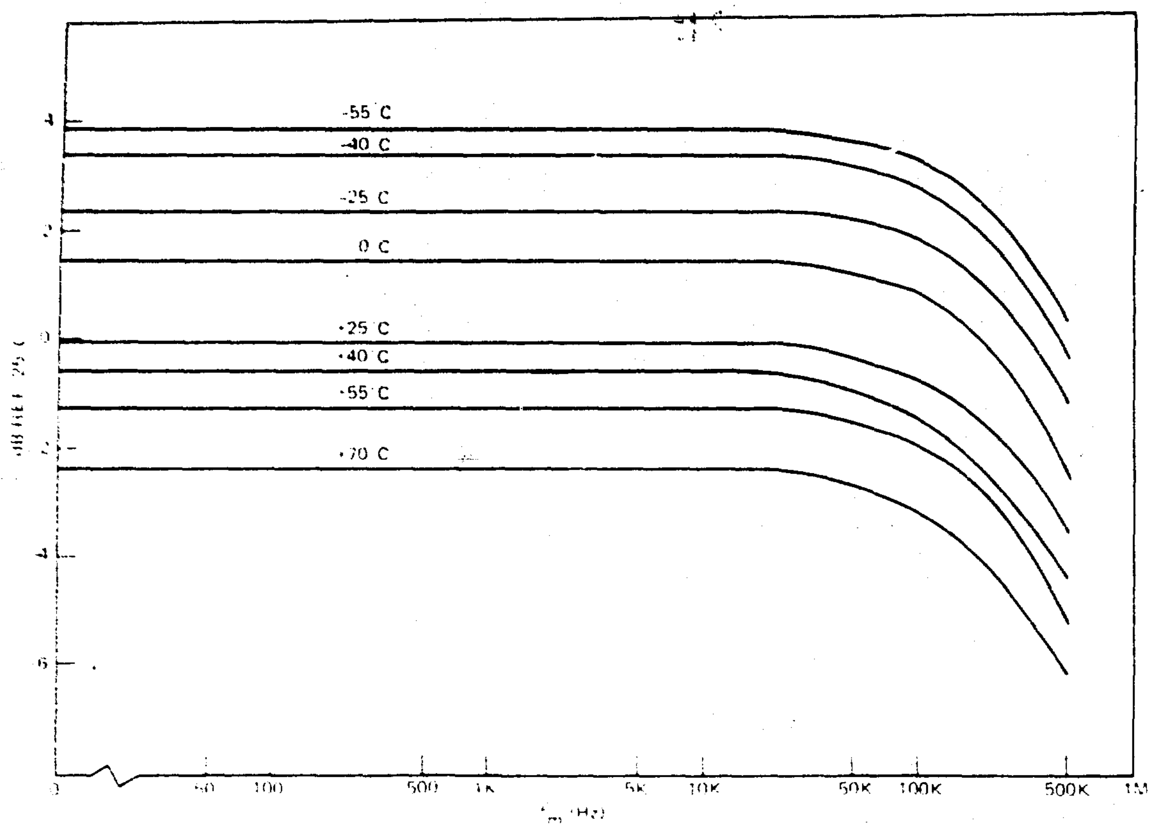

Figure B-1. ML-36 power output vs. frequency and temperature. I_f = 100ma (constant)

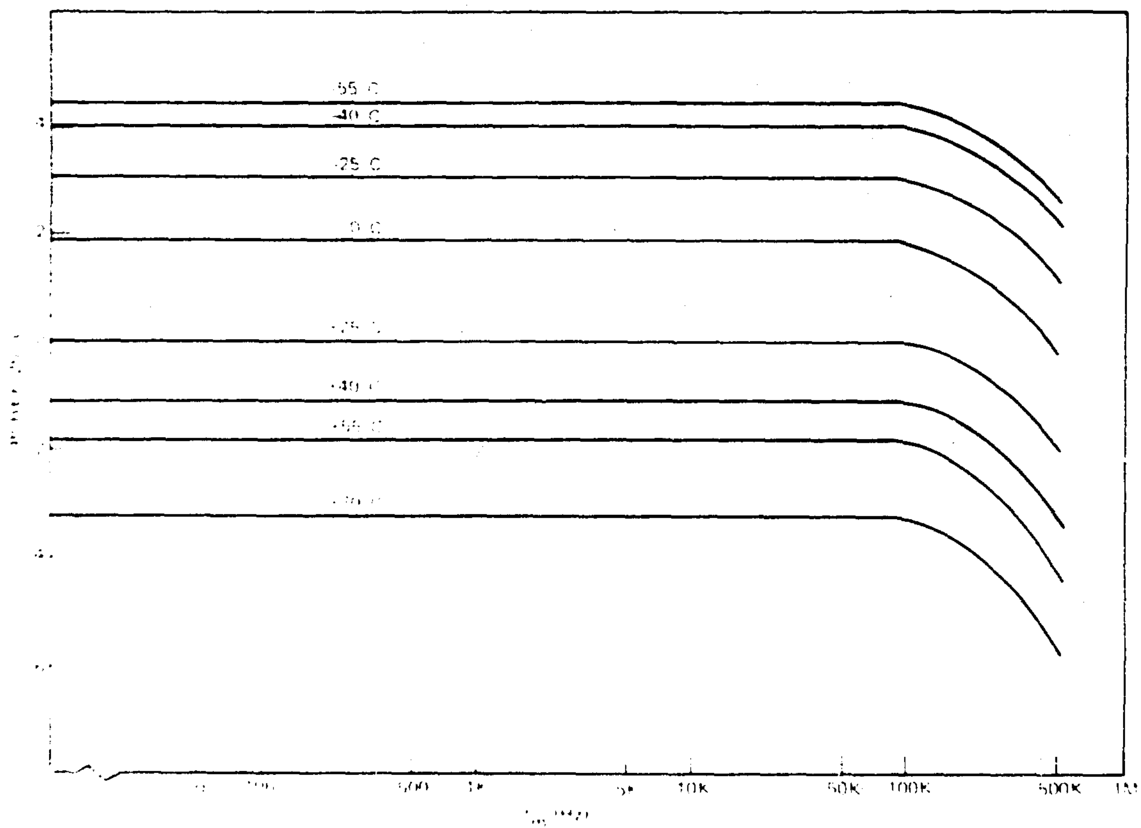

Figure B-2. SSL-56 power output vs. frequency and temperature. I_f = 100ma (constant)

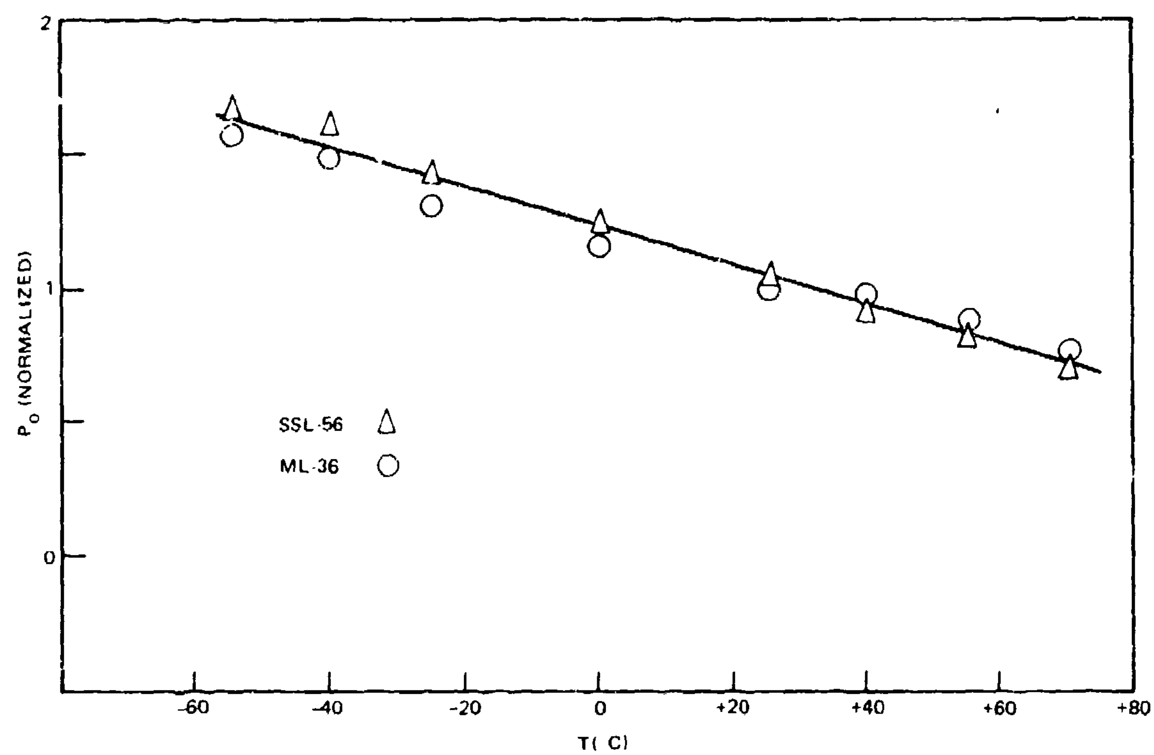

Figure B-3. Power output vs. temperature f_m = constant; I_f = 100ma

APPENDIX C

SECTIONS OF SPECIFICATION MIL-T-5422F

TABLE 2. TEST CHAMBER CONDITIONS FOR TEMPERATURE-ALTITUDE TESTS

	Class	Step	1a	1b	2	3	4	5	6	7	8	9	10	11	12	13	14
MIL-E-5400	1	Temp (°C) Alt (ft) Time	Omit	-62 ATM 2 hr	-54 ATM	-54 50,000 —	-10 ATM —	85 ATM 16 hr	55 ATM 4 hr	71 ATM 30 min	Omit	30 40,000 4 hr	47 40,000 30 min	20 50,000 4 hr	35 50,000 30 min	Omit	Standard Ambient Conditions
	1A	Temp (°C) Alt (ft) Time	Omit	-62 ATM 2 hr	-54 ATM —	-54 30,000 —	-10 ATM —	85 ATM 16 hr	55 ATM 4 hr	71 ATM 30 min	Omit	48 20,000 4 hr	64 20,000 30 min	40 30,000 4 hr	57 30,000 30 min	Omit	
	2	Temp (°C) Alt (ft) Time	Omit	-62 ATM 2 hr	-54 ATM —	-54 70,000 —	-10 ATM —	95 ATM 16 hr	71 ATM 4 hr	95 ATM 30 min	Omit	36 50,000 4 hr	60 50,000 30 min	10 70,000 4 hr	35 70,000 30 min	Omit	
	3	Temp (°C) Alt (ft) Time	Omit	-62 ATM 2 hr	-54 ATM —	-54 80,000 —	-10 ATM —	125 ATM 16 hr	95 ATM 4 hr	125 ATM 30 min	150 ATM 10 min	60 50,000 4 hr	90 50,000 30 min	-10 100,000 4 hr	20 100,000 30 min	45 100,000 10 min	
	4	Temp (°C) Alt (ft) Time	Omit	-62 ATM 2 hr	-54 ATM —	-54 80,000	-15 ATM —	150 ATM 16 hr	125 ATM 4 hr	150 ATM 30 min	260 ATM 10 min	90 50,000 4 hr	115 50,000 30 min	25 100,000 4 hr	50 100,000 30 min	155 100,000 10 min	
MIL-T-21200	1	Temp (°C) Alt (ft) Time	Omit	-62 ATM 2 hr	-54 ATM —	-54 50,000 —	-10 ATM —	85 ATM 16 hr	55 ATM 4 hr	71 ATM 20 min	Omit	30 40,000 4 hr	47 40,000 20 min	20 50,000 4 hr	35 50,000 20 min	Omit	Standard Ambient Conditions
	2	Temp (°C) Alt (ft) Time	25 50,000 1 hr	-62 ATM 2 hr	-40 ATM —	-40 10,000 —	-10 ATM —	85 ATM 16 hr	55 ATM 4 hr	71 ATM 20 min	Omit	52 10,000 4 hr	68 10,000 20 min	Omit	Omit	Omit	
	3	Temp (°C) Alt (ft) Time	25 50,000 1 hr	-62 ATM 2 hr	0 ATM —	0 10,000 —	Omit	85 ATM 16 hr	55 ATM 4 hr	Omit	Omit	52 10,000 4 hr	Omit	Omit	Omit	Omit	

Figure C-1. Temperature-altitude test steps (Table II).

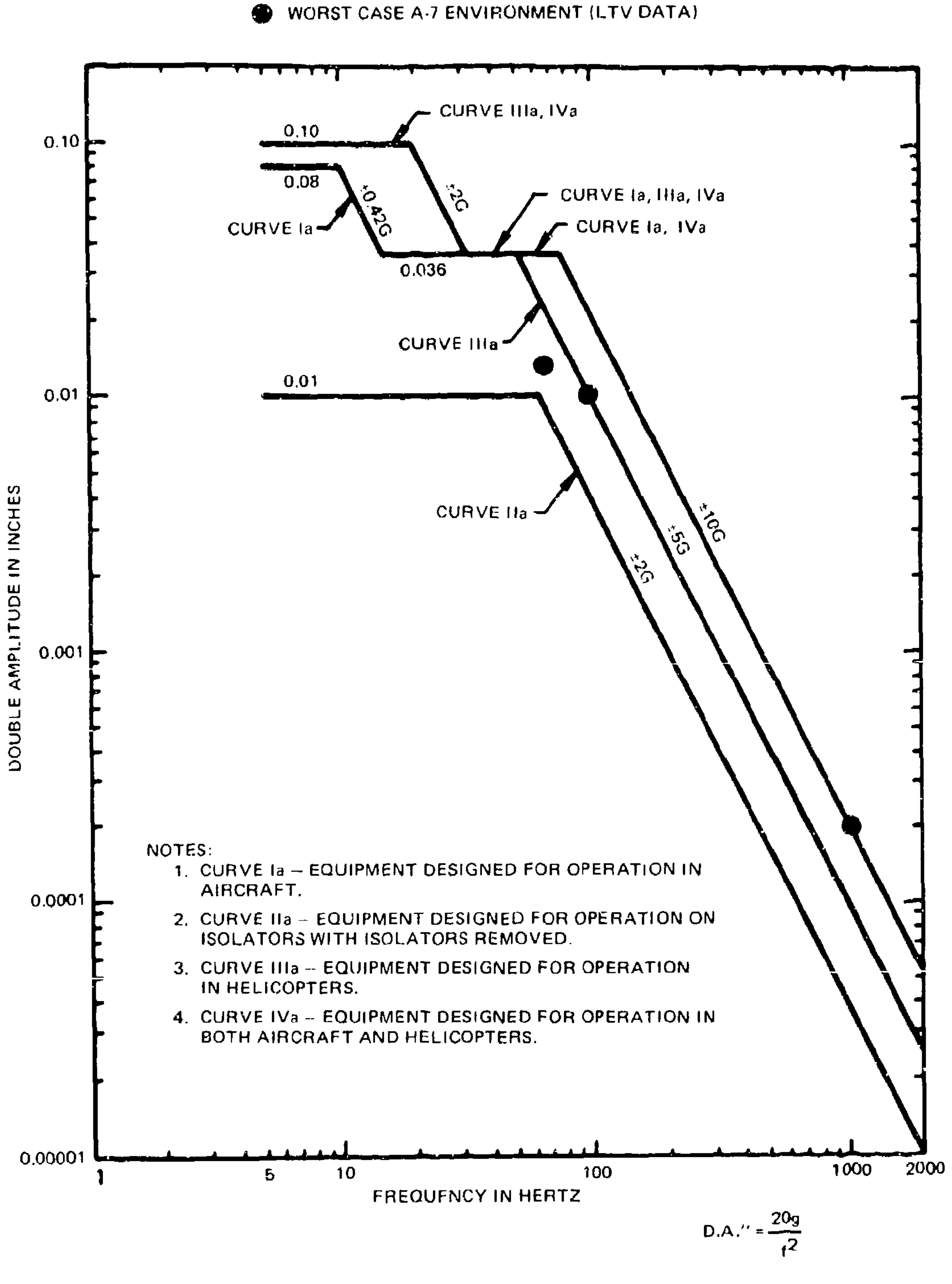

Figure C-2. Vibration curve (including LTV-supplied data) (Figure 6).

TABLE 1. TEMPERATURE RANGE FOR VARIOUS EQUIPMENT CLASSES

Equipment Classes			Equipment Mode				
			Operating				
	No.	Altitude Range (ft)	Contin-uous	Intermit-tent	Short-Time	Non-Operat-ing	Temperature (°C)
MIL-E-5400	1	Sea Level to 50,000	X				-54 to 55
				X			55 to 71
						X	-62 to 85
	1A	Sea Level to 30,000	X				-54 to 55
				X			55 to 71
						X	-62 to 85
	2	Sea Level to 70,000	X				-54 to 71
				X			71 to 95
						X	-[illegible] to 95
	3	Sea Level to 100,000 (95°C Continuous Sea Level Operation)	X				-54 to 95
				X			95 to 125
					X		125 to 150
						X	-62 to 125
	4	Sea Level to 100,000 (125°C Continuous Sea Level Operation	X				-54 to 125
				X			125 to 150
					X		150 to 260
						X	-62 to 150
MIL-T-21200	1	Sea Level to 50,000	X				-54 to 55
				X			55 to 71
						X	-62 to 85
	2	Sea Level to 10,000	X				-40 to 55
				X			55 to 71
						X[1]	-62 to 85
	3	Sea Level to 10,000	X				0 to 55
						X[1]	-62 to 85

[1] Air transporation to 50,000 ft.

Figure C-3. Temperature range (Table 1).

TABLE VIII. ENVIRONMENTAL TEST VS. EQUIPMENT CLASSES

Test	Procedure Page No.	Equipment Class per MIL-T-21200			Equipment Class per MIL-E-5400				
		1	2	3	1	1A	2	3	4
Temperature-Altitude	7	a	a	a	a	a	a	a	a
Vibration	19	a	a	a	a	a	a	a	a
Shock	33	a	a	a	a	a	a	a	a
Humidity	36	a	a	a	a	a	a	a	a
Salt Fog	39	a	a	c	a	a	a	a	a
Explosion	44	a	a	a	a	a	a	a	a
Sand and Dust	49	b	b	c	b	b	b	b	b
Fungus	51	b	b	b	b	b	b	b	b
Temperature Shock	55	c	c	c	b	b	b	b	b
Bench Handling	57	c	c	c	c	c	c	c	c
Drip-Proof	58	c	a[1]	c					
Watertight	59	a[2]	a[2]	a[2]					
Drop	60	a[2]	a[2]	a[2]					
Acoustical Noise	62	b	b	b					

a. Environmental requirement contained in MIL-E-5400 (or MIL-T-21200) and test contained herein is applicable when this specification is envoked unless specifically not required by the detail equipment specification or the procuring agency.

b. Environmental requirements contained in MIL-E-5400 (or MIL-T-21200) but test contained herein is not applicable when this specification is envoked unless specifically required by the detail equipment specification or the procuring agency.

c. Not standard environmental requirement of MIL-E-5400 (or MIL-T-21200). These tests are applicable only when specifically required by the detail equipment specification or the contract.

[1] Equipments housed in combination cases.
[2] Transit cases or equipment housed in combination cases.

Figure C-4. Test list (Table VIII).

APPENDIX D

TEMPERATURE-ALTITUDE DATA

FREQUENCY RESPONSE

Photographs were taken of the light output of System 1 at frequencies of 100 KHz, 1 MHz, and 10 MHz. The LED module power supply was 5.0 volts. The input voltage was 0.8 volts for "0" and 2.0 volts for "1" logic levels. Inputs at 1 MHz are shown in the top trace of each figure. The output of the system is shown in the bottom trace of each figure as it was detected by a silicon avalanche photo-diode (TIXL55) operated at 180 volts.

Table D-1 shows the power output of the LED system versus temperature and altitude. Table D-2 is the dc power output for worst case "0" and "1" levels.

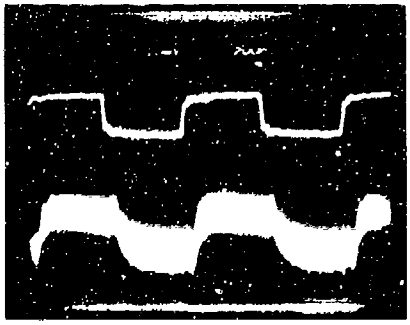

Figure D-1. System output at 95°C and at sea level.

Figure D-2. System output at 85°C at sea level.

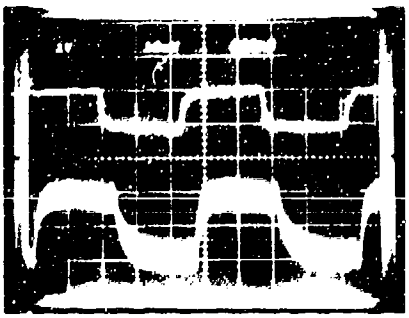

Figure D-3. System output at 71°C at sea level.

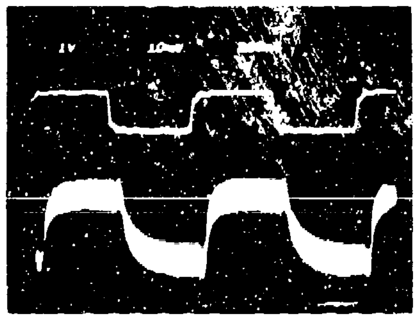

Figure D-4. System output at 28°C at sea level after completion of all temperature-altitude tests.

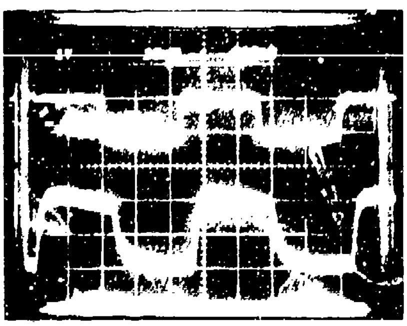

Figure D-5. System output at -54°C at 70,000 feet.

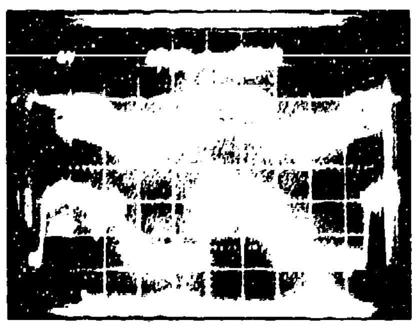

Figure D-6. System output at -54°C at sea level.

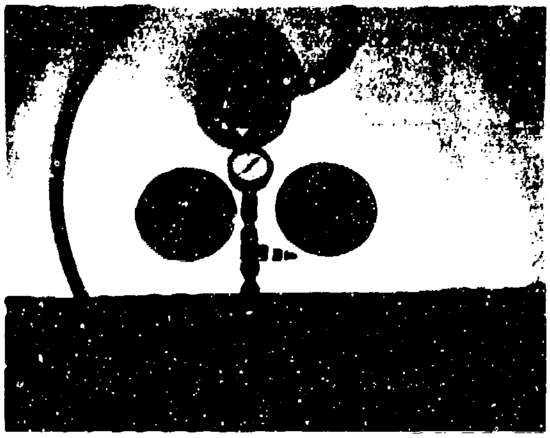

Figure D-7. Test fixture.

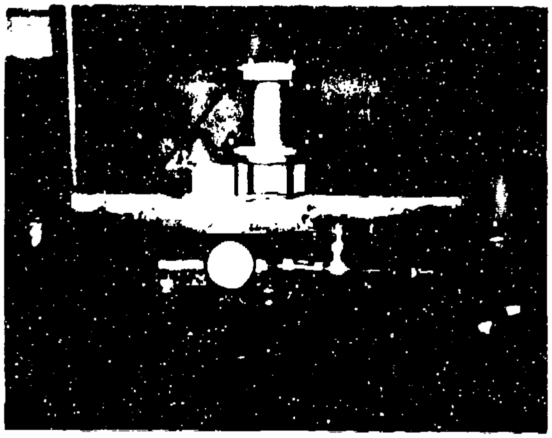

Figure D-8. System 1 on vibration and shock mount.

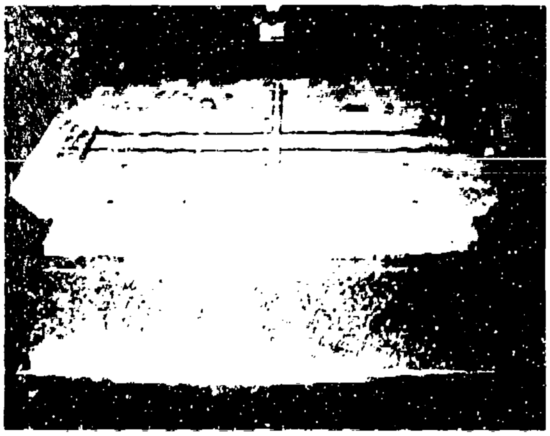

Figure D-9. Fiber-optic cable vibration mount.

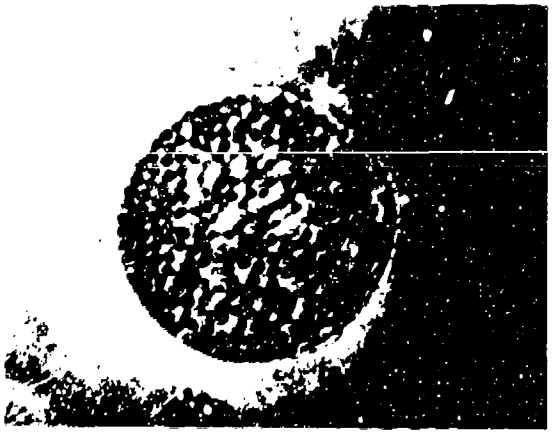

Figure D-10. Epoxy extrusion after high-temperature tests.

TABLE D-1. LED SYSTEM POWER OUTPUT VERSUS TEMPERATURE AND ALTITUDE

Light Output Power

dc(μW)	100KHz	1MHz	10MHz	T_{case}	$T_{heatSink}$	T_{air}	Altitude	V_{power}	V_{signal}
15.0				-39°C	-48°C	-54°C	s.l.	5.25	4.0
14.0				-43°C	-48°C	-54°C	s.l.	5.0	2.5
13.5	7.2	5.4	4.9	-42.5°C	-49°C	-54°C	70K	5.0	2.5
12.8	7.2	7.3	5.75	-17°C	-36°C	-54°C	70K	5.25	4.0
12.0		6.15		-42°C	-49°C	-54°C	s.l.	4.75	2.0
8.4	4.8	5.1	4.0	31°C	17°C	-10°C	s.l.	5.25	4.0
7.6				33°C	25°C	+10°C	s.l.	5.25	4.0
7.25	4.9	5.2	4.7	41°C	25°C	+10°C	70K	5.25	4.0
6.75	3.7	4.2	3.1	42°C		25°C	s.l.	5.0	2.5
6.55	4.25	4.55	4.0	38°C	29°C	28°C	s.l.	5.25	4.0
6.4		3.8		52°C	39°C	32°C	s.l.	5.0	2.5
6.1				58°C	51°C	36°C	s.l.	5.25	4.0
5.75	3.75	4.0	3.5	52°C	48°C	25°C	s.l.	5.0	2.5
5.5				66°C	51°C	35°C	70K	5.25	4.0
5.33		3.75		67°C	53°C	36°C	50K	5.25	4.0
5.20				73°C	62°C	36°C	50K	5.25	4.0
5.15		3.45		64°C	53°C	36°C	50K	5.0	2.5
4.3	2.75	3.0	2.8	82°C	75°C	71°C	s.l.	5.25	4.0
4.25				84°C	76°C	71°C	s.l.	5.25	4.0
4.3				85°C	78°C	60°C	s.l.	5.25	4.0
3.9				94°C	85°C	60°C	50K	5.25	4.0
3.6				91°C	82°C	85°C	s.l.	5.25	4.0
3.25	2.1	2.3	2.1	94°C	86°C	85°C	s.l.	5.25	4.0
2.7	1.75	1.9	1.75	101°C	96°C	95°C	s.l.	5.25	4.0
2.55	1.70	1.85	1.70	102°C	96°C	95°C	s.l.	5.25	4.0

TABLE D-2. DC POWER OUTPUT FOR WORST CASE "1" AND "0" LEVELS.

digital "1" = 2.0 volts digital "0" = 0.8 volts					
	$V_{power\ supply}$ = 4.75 volts		$V_{power\ supply}$ = 5.25 volts		
T_{air}	V_{in} = 0.8V	V_{in} = 2.0V	V_{in} = 0.8V	V_{in} = 2.0V	
-54°C	2.8μW	12.3μW	3.4μW	14.7μW	
-54°C @ 70K ft	2.6	11.0	3.15	13.0	
10°C	1.55	6.75	1.85	7.80	
25°C	1.20	5.3	1.45	6.15	*T_{case} = 52°C
28°C	1.25	5.65	1.55	6.60	*T_{case} = 38°C
35°C	1.25	5.40	1.55	6.18	
35°C @ 70K ft	1.15	4.8	1.40	5.45	
60°C	1.0	4.10	1.2	4.6	
60°C @ 50K ft	0.90	3.8	1.10	4.30	
71°C	0.86	3.60	1.05	4.15	
85°C	.76	3.15	0.92	3.62	*T_{case} = 91°C
85°C	.68	2.80	0.84	3.20	*T_{case} = 94°C after 16 hours
95°C	.56	2.35	0.70	2.65	
95°C	.56	2.2	0.68	2.60	after 16 hours storage

*The ratio of "1" to "0" levels are ~4:1 at all temperatures. The LED was driven by four gates on an integrated circuit in the LED module. One of the gates was always on. This condition existed before all tests began.

APPENDIX E

TYPICAL SYSTEM WARMUP RESPONSES

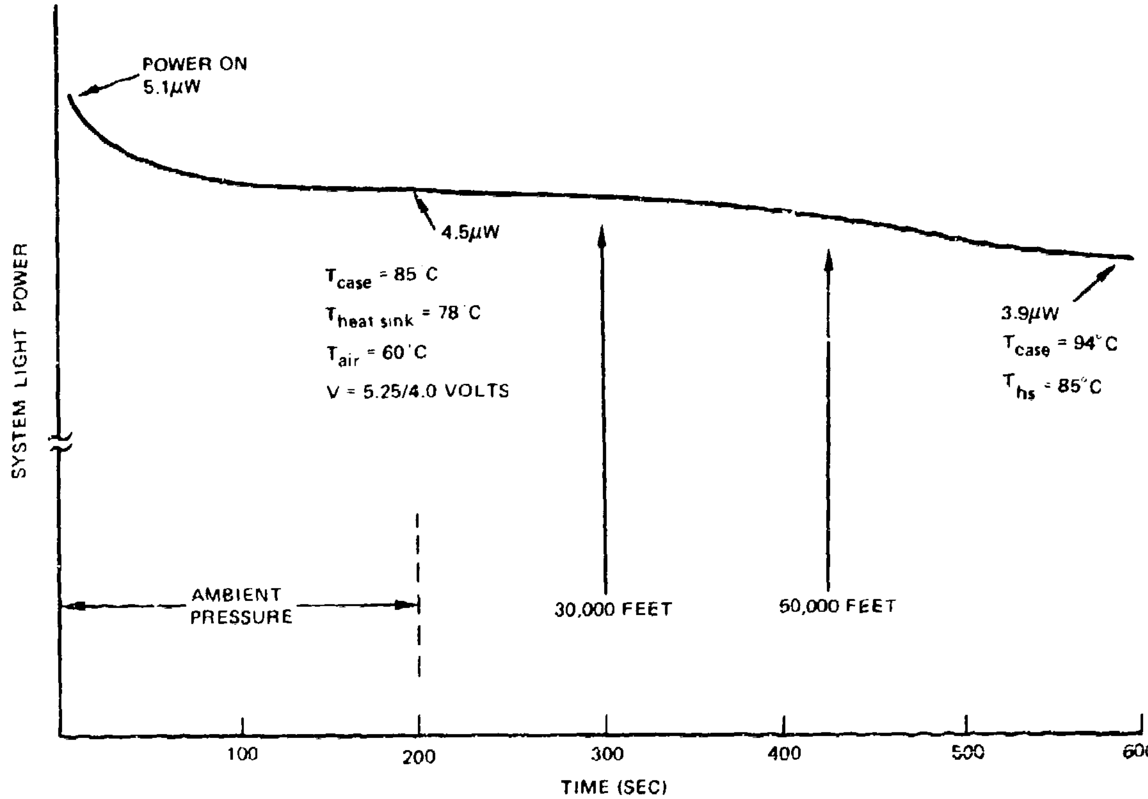

Figure E-1. Light output power decrease with heatup. First decrease after turnon, second decrease after changing altitude.

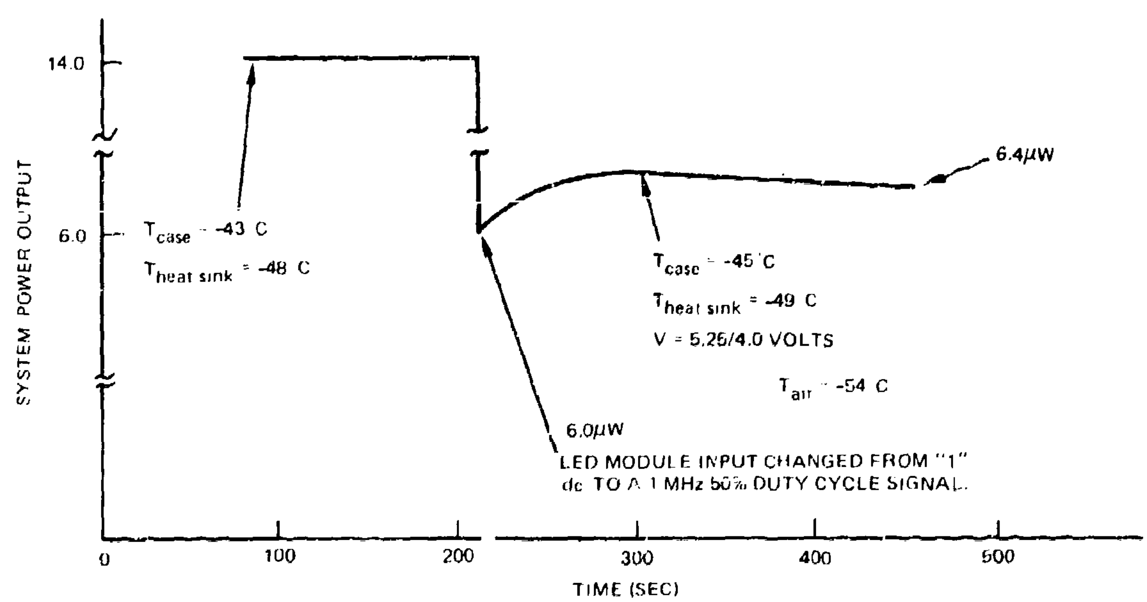

Figure E-2. Light output power increase as the LED module cools (changing from 100% to 50% duty cycle).